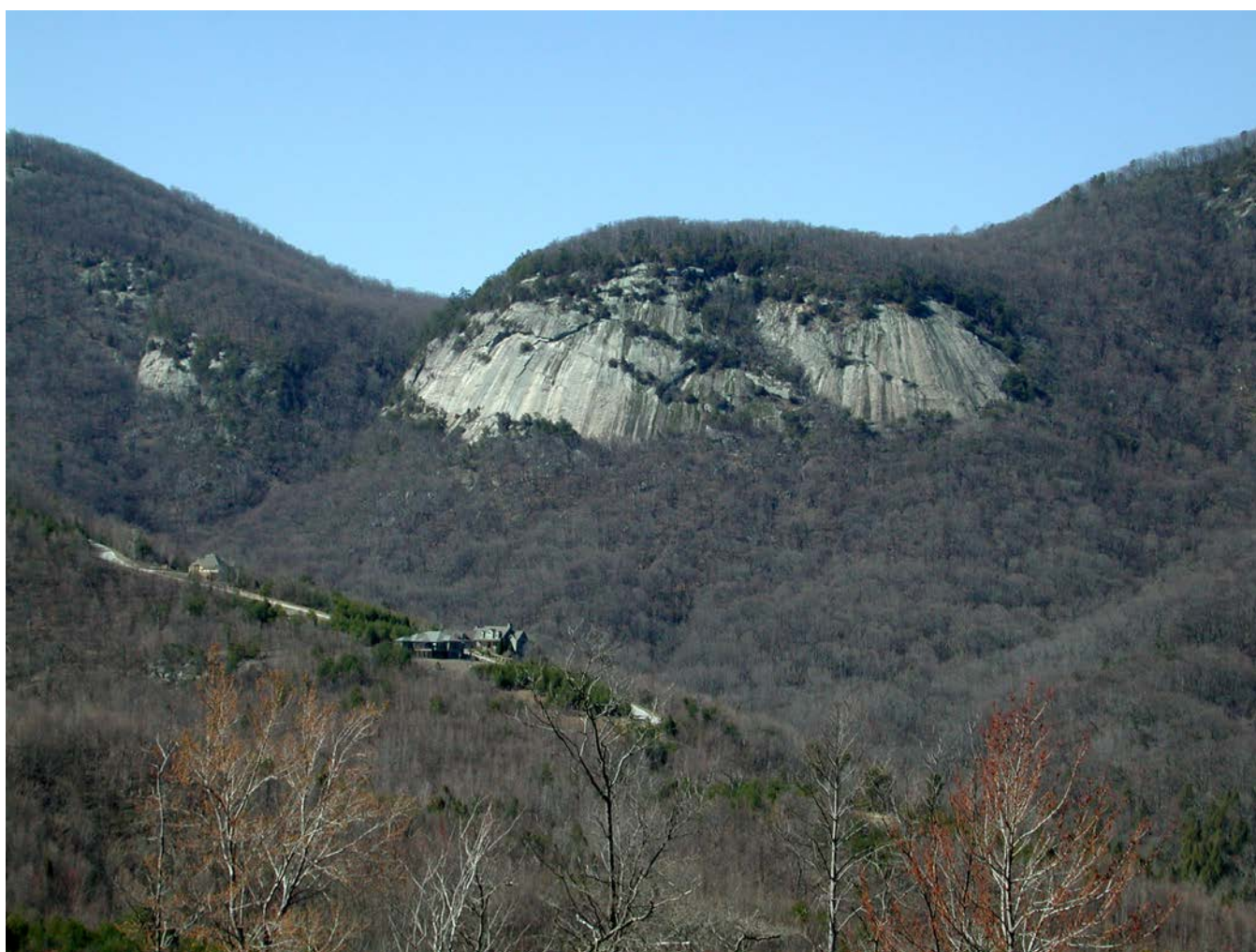


**The 18<sup>th</sup> Annual David S. Snipes/Clemson Hydrogeology  
Symposium Field Trip Guidebook**

**Geology and Hydrogeology of the Pax  
Mountain/The Cliffs at Glassy/Landrum area,  
Greenville and Spartanburg Counties,  
South Carolina**



Round Mountain exfoliation dome or bald (summit 850 m elevation) along the Blue Ridge Escarpment. Homes of The Cliffs at Glassy community in the middle distance. View to the north.

**Field Trip Leaders: John M. Garihan, Cameron M. Warlick, and William A. Ranson  
March 31/April 2, 2010**

The 2010 Clemson University Hydrogeology Symposium Field Trip Guide is dedicated to **Dr. David S. Snipes** for his contributions to the understanding of the Hydrogeology of Upstate South Carolina

**Personal Reflections on Pax Mountain Research with  
Dr. David S. Snipes**

Jerry A. Wylie, PG (BS Geology, Clemson – 1984)

It is hard to conceive that it has been over 25 years since I worked with Dr. Snipes on his Pax Mountain research. To say that it seemed like only yesterday would be cliché, but sometimes clichés can be accurate. David Snipes was a mentor, a teacher, and a friend, and I enjoy opportunities to share with others the stories of our experiences together. Dave's legacy lives on in many ways – through his former students, his professional colleagues, his family, his many friends, and of course, through this Symposium whose name so appropriately honors his memory and professional legacy.

I still have very clear memories of our experiences during the Pax Mountain work. For this year's Snipes Hydrogeology Symposium Field Trip Guidebook, I want simply to offer a few anecdotes and memories about the time we spent on Pax Mountain-related work. I want readers of this Guidebook and participants on the field trip to recognize the connection that recent research on Pax Mountain has with Dr. Snipes. Geologists, common to all scientists, build our understandings of the planet and our place in it on the foundation provided by those hard-working, smart, creative minds that go before us. That is certainly the case with Pax Mountain-related research as is evidenced by studies conducted and reported in subsequent years (Garihan and others, 1990; Doar, 1998; Clendenin and Garihan, 2001; Soricelli, Clendenin, and Castle, 2003; and the work that went into this current volume). A second reason for sharing these memories is to introduce David Snipes to those readers who did not have the privilege of knowing or meeting him. Dave was truly a larger-than-life personality, but more importantly, he was also an excellent scientist and an outstanding teacher and mentor.

In short summary, when I think of my time working with Dave at Pax Mountain, a number of disparate subjects come to mind: the desert, ticks, dolerite, wells, and TV "stardom." I can dispense with one of these subjects quickly. Simply stated, we were fortunate to be working in northern Greenville County, not in the Snipes-coined region known as the "Great Western North Carolina Desert." For those who have never heard of this region, the "Great Western North Carolina Desert" was an encompassing term Dave used for some of the mountain counties of western North Carolina that were "dry" – that is, they did not allow alcohol sales within the county. I will state it again: thankfully, Pax Mountain is not located in western NC. I'll just leave it at that.

On the other hand, we were also unfortunate to be working in northern Greenville County. An entomologist colleague of Dave's informed him that statistically one out of every ten ticks in the northern part of Greenville County carried Rocky Mountain spotted fever. This bit of statistical trivia greatly intrigued Dave, but it practically sent me into a state of complete immobilization from fear. A state of fear was not good for one of Dr. Snipes' students because we were always expected to take machete in hand and hack through the

most densely vegetated environs in the study area. How else could our esteemed professor possibly see the rocks and soil without good line of sight? To this day, I laugh at those fearful of snakes and spiders and other critters. But, find a tick on me, and I squeal like a little girl at a Jonas Brothers concert.

I worked on Pax Mountain research after much of the geologic mapping had been completed by Snipes, Mike Davis, and Peter Manoogian. As I began to get more involved with the work, and we made more and more trips to the area, Snipes patiently related information and interpretation about the local geology that he and previous students had developed through their mapping work. At the time, almost as an aside to the main purpose for which we were working on Pax Mountain, both Snipes and I were intrigued by the dolerite (diabase) dikes that the team had mapped in the Pax Mountain area. These dikes were obviously of great importance for age-dating activity/displacement along the Pax Mountain fault. Beyond this importance, however, Dave and I had been working on a mapping/groundwater supply project in Greenwood County and Abbeville County, South Carolina. During our work there, we had discovered several significant dolerite dikes, and Snipes and Dr. Richard Warner (Clemson University) had begun to discuss research opportunities centered on the mineralogy of these contemporaneous dikes found throughout the region. Those discussions would lead to several papers on the subject (Warner and others, 1985; Warner and others, 1986). To this day, I can identify the presence of dolerite float and the subtle topographic indications of a dolerite dike in an instant.

The primary focus of my time involved in the Pax Mountain research centered on issues of groundwater quality in the area. Dave had been doing a good bit of funded research on the problem of groundwater supply in the Piedmont and Blue Ridge. (In fact, Dave was interviewed by *Clemson World* on the subject in 1981. I still have a copy of that issue!) In the early 1980s, the area was quite undeveloped. Several property owners, however, had figured out that Pax Mountain was a desirable place to build a home: great views, secluded, and far enough away from Greenville, yet close enough to Greenville. There was only one problem: they decided to build their dream homes on the crest of a Mesozoic fault comprised of silicified/recrystallized fault breccia mixed with unconsolidated fault-generated clay gouge. I'm pretty certain that little tidbit of information was not included in the real estate listing! Obtaining useful and usable groundwater, both from a quantity and quality standpoint, was proving to be extremely difficult and extremely expensive as dry hole after dry hole was drilled in a vain search for water supply. We made numerous trips to the area where we mapped, observed drilling and studied drill cuttings, and visited with homeowners and listened to their concerns. The paper that resulted from the research was published in 1986 (Snipes and others, May-June 1986) and summarizes the breadth of subjects that were researched to address this specific groundwater supply problem. The research, and subsequent paper, synthesized evidence and data from the realms of hydrogeology, structural geology, mineralogy (including clay mineralogy), geochemistry, and drilling/water well construction techniques and methods. What a rare experience for a Geology undergraduate student to be exposed to so many geologic specialties and to work with a seasoned researcher while he wove the observations and data into a cohesive and relevant whole.

Right about the time I graduated from Clemson, Dave was approached about filming a short piece for an ETV television show. I don't recall the overall theme of the show, but I do recall that this was to be "on location", and Snipes was to meet the interviewer and the camera crew at Pax Mountain. But, Dr. David Snipes, in the gracious and honorable manner

that he had with his students, asked me to be a part of the taping. He wanted me, a recent B.S. graduate who was still several months away from his first graduate school Geology course, to be filmed describing the fault gouge and the difficulty it presented in the pursuit of usable supplies of groundwater for homeowners. He wasn't the star of the show; the rocks and the science were! He was mostly concerned with getting important scientific information out to the general public and to making sure that one of his students had an opportunity to do something different that might one day help his development as a professional. I remember filming the interview (one take, thank you very much), and I remember how surprisingly nervous I was. Dave made sure I got a copy of our segment after it aired, and I still have that old VHS tape!

There are a number of us out there – former students of David Snipes who owe him so much for the manner in which he treated us, for the way in which he encouraged us and challenged us, and for the way he got us on the right path to careers as geologists. For the time I spent there and for the work and experiences that I had there with Dave and others, Pax Mountain will always be a special and memorable place to me.



Dave Snipes holding court at an outcrop in Oconee County, SC, 1983.  
Photo courtesy of Jerry Wylie.



# **Geology and Hydrogeology of the Pax Mountain/The Cliffs at Glassy/Landrum area, Greenville and Spartanburg Counties, South Carolina**

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Field trip leaders: John M. Garihan, Cameron M. Warlick, and William A. Ranson

## **INTRODUCTION**

The purpose of this field guide covering the Pax Mountain-The Cliffs at Glassy-Landrum area, South Carolina is to provide a brief synopsis of relevant background information for the participants of the March 31 and April 2, 2010 Field Trips of the 2010 Clemson University Hydrogeology Symposium. Geologic and hydrologic information is based on: 1) recently completed geologic maps of Tigerville, Landrum, and Saluda 7.5-minute quadrangles (Garihan and others, 2009; Garihan, 2009a) and 2) a Master's thesis, a paper (Warlick and others, 2001), and continued professional work with The Cliffs at Glassy community by Cameron Warlick. The stops for the field trip are shown in Figure 1.

The study area lies along a scenic, rugged portion the Blue Ridge Escarpment (locally 1500 feet of relief). Appreciable growth in the number of new homes, support services, and property values has developed in the past 25-30 years (Figure 2). In the early 1980's when geologic mapping began, no paved roads were present on Pax Mountain or as access to the top of Glassy Mountain. Only rutted roads in saprolitic gneiss allowed hang glider enthusiasts to launch from the rounded balds of gneiss along the Escarpment to an open landing area below on Route 11. A drainage divide bordering the restricted-access Greenville Watershed area lies immediately north of The Cliffs at Glassy community. West-flowing streams there south of the state line feed the Poinsett (North Saluda) Reservoir, a major regional surface water supply for the upstate. Environmental protection of this water supply resource is an on-going concern for all who utilize the surface water and ground water and hike in the area. The Heritage Trust Blue Wall Preserve has provided hiking trails in the area east of The Cliffs community, restricting further housing development. Water supply lakes for Landrum, SC also lie at the base of the Escarpment.

Inner Piedmont mapping in upstate South Carolina has focused traditionally on compressive structures, particularly thrust faults. One goal of this field excursion is to demonstrate that brittle faults are far more significant in the development of the Piedmont landscape as it now appears. Moreover, occasional small magnitude earthquakes ( $m=2+$ ) do occur in the state line area, for example one near Columbus, North Carolina several

years ago. Therefore, there is potential for seismic and accompanying landslide risk in this developing area where homes are constructed in mountainous areas along the steep edge of the Escarpment.

Figure 1. Index map for stops on the field trip.

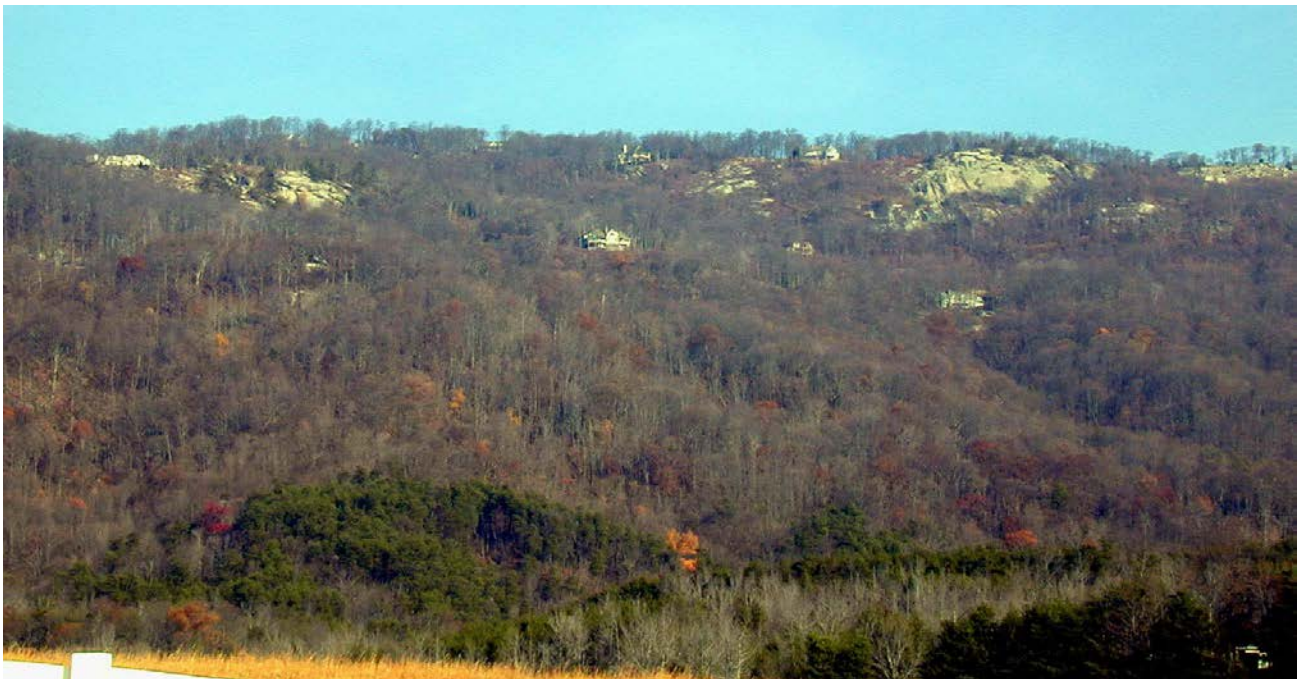


Figure 2. The Cliffs at Glassy homesites on the south-facing slopes of the Blue Ridge Escarpment. Photograph taken from Rt. 11 in December, 2007.

## PATTERN OF REGIONAL FAULTING

Regional geologic mapping in fourteen quadrangles between Salem and Landrum, SC (east-west) and Greenville, SC and Zirconia, NC (north-south) has traced a complex system of numerous brittle faults and associated siliceous cataclastic rocks across the Inner Piedmont landscape (shown in part in Figure 3). The faults lie southeast of the Brevard fault zone, the Eastern Blue Ridge-Inner Piedmont structural boundary. The brittle faults we will see and describe complexly dissect and displace a stack of three major Paleozoic thrust sheets composed of Neoproterozoic and Paleozoic metamorphic rocks. A regional compilation of ductile and brittle faults (Garihan, 2009b) is available on the SCDNR website. (<http://www.dnr.sc.gov/geology/publications.htm>)

These regional faults, initially described as the Marietta-Tryon fault system (Garihan and Ranson, 1988; Garihan and others, 1988, 1990), strike northwest, northerly, easterly, and northeast. The latter is the dominant fault orientation regionally (N50°-70°E). The faults and similarly oriented fractures and joints locally have influenced directions of stream downcutting and the subsequent erosional development of topography. Their influence on water availability and flow in fractured crystalline rock media at The Cliffs will be described on this trip. Landrum, SC lies within a conspicuous south-opening topographic embayment of the Blue Ridge Escarpment. Erosion along northerly and northwesterly faults in Landrum quadrangle may be at least partly responsible for the development of this embayment in the Escarpment (Garihan, 2009a).

Based on mutual fault relationships that can be discerned in Saluda, Landrum, and Tigerville quadrangles (Figure 3), a chronology of fault development can be determined that post-dates widely recognized Paleozoic thrust faulting. Oldest to youngest the proposed faulting sequence is: 1) northwest and northeast faults; 2) silicified cataclastic rock development (for example, at Pax Mountain); 3) northeast faults; 4) north to north-northwest faults; and 5) more silicified cataclastic rock development (for example the northeast-striking zone of cataclastic rock in Landrum quadrangle).

Many northwest faults have normal or oblique-normal movements in the field trip area (Figure 3). Two major down-to-the-east normal faults mark the eastern limit of Seneca thrust footwall Table Rock gneisses appearing at the surface. That is, the regionally extensive Walhalla nappe containing these orthogneisses terminates against these normal faults. East of the faults, only hanging wall Six Mile thrust sheet rocks (Tallulah Falls formation gneisses, schist, and amphibolite) appear in Landrum quadrangle.

## GEOCHRONOLOGY OF GNEISSES (W. A. Ranson)

Detailed mapping in Upstate South Carolina along the Blue Ridge escarpment has focused on the metamorphic stratigraphy and structural history of the region, but the timing and provenance of abundant biotite gneisses remains problematic. Numerous biotite gneiss units crop out in the region, including Henderson Gneiss, Tallulah Falls Formation, and Table Rock gneiss. Distinguishing among these biotite gneisses in the field has proven difficult. SHRIMP zircon ages from two samples (one of Table Rock gneiss near Caesars Head and a second of Tallulah Falls gneiss from exposures along Rt. 25 south of the SC-NC state line) yield a Mid to Late Ordovician age for both gneiss units, despite the fact that they are located, respectively, on footwall and hanging wall sides of the regional Seneca fault.

BIG MAP 11 x 17



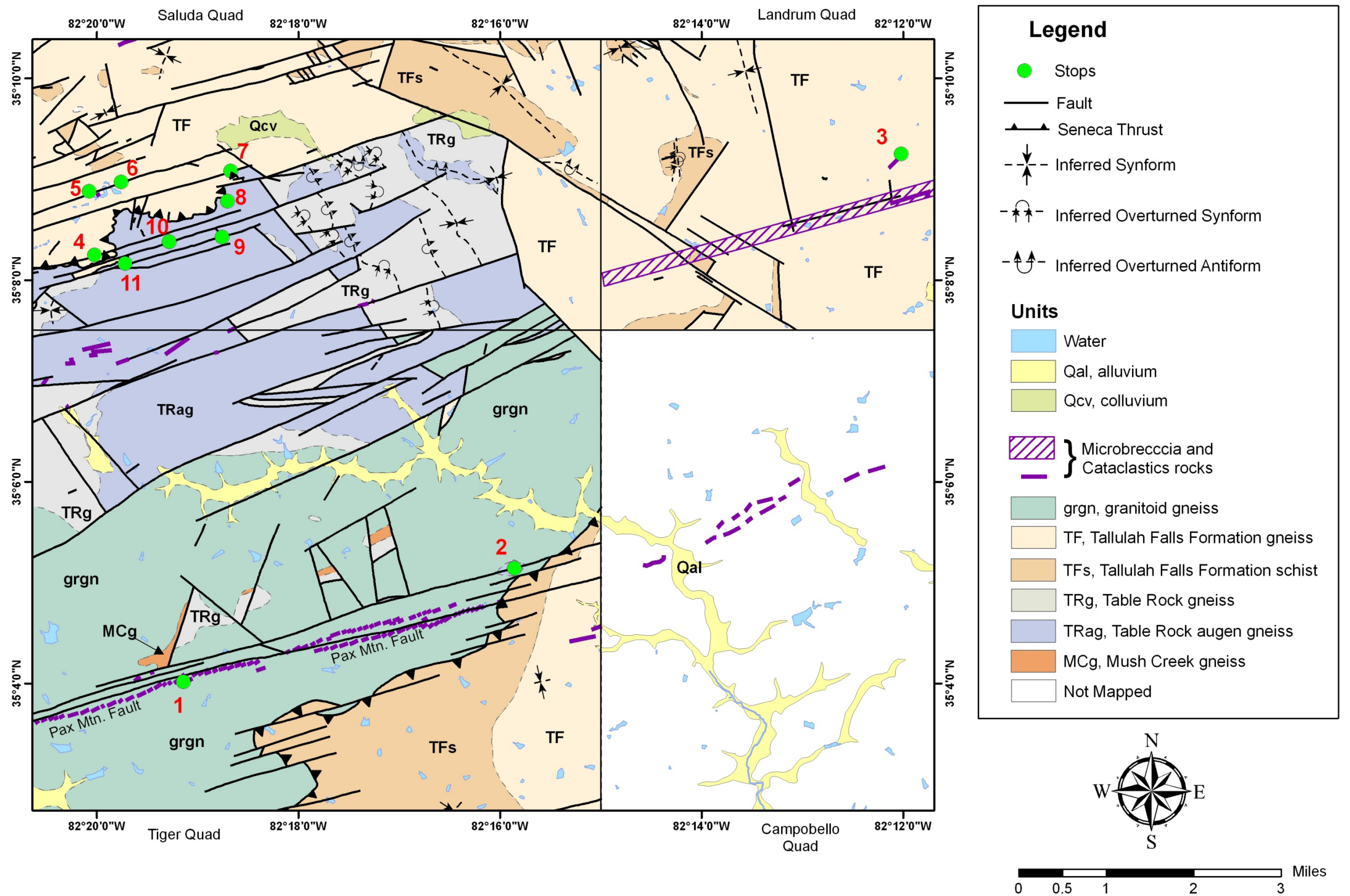


Figure 3. Geologic map of parts of Saluda, Landrum, and Tigerville quadrangles, upstate South Carolina. Rocks in the footwall of the Seneca fault (Table Rock plutonic suite orthogneisses, Trg and Trag) are part of the Walhalla nappe of Griffin (1974). Tallulah Falls Formation rocks above the Seneca fault are part of Griffin's Six Mile thrust sheet.

The Table Rock gneiss, which forms extensive pavement exposures at Table Rock, Bald Rock, and Caesars Head in the Table Rock and Cleveland 7.5-minute quadrangles and other locations along the Blue Ridge escarpment, is a contorted, medium-crystalline, biotite, feldspar augen gneiss (quartz, K-feldspar, biotite, minor plagioclase,  $\pm$  hornblende). It is multiply folded and displays transposed foliation. Augen gneiss mapped within the footwall here and in adjacent quadrangles in many places bears a strong resemblance to the Henderson Gneiss. The latter has been dated west of the field trip area near Salem, SC at 445 Ma (Fullagar and others, 1997), very similar to the ages reported here, leaving open the possibility that the footwall gneisses indeed are part of the Henderson. Only one of ten zircons examined in Table Rock gneiss had a core, which yielded a late Proterozoic age (Ranson and others, 1999).

The Table Rock gneiss at Bald Rock contains enclaves of fine-crystalline, leucocratic, poorly foliated, biotite gneiss. Enclaves are 0.3-0.5 m wide, up to 5 m long with tapered ends, irregular shape along their length, and internal folding of gneissic banding on mm-cm scale. Contacts with the country rock are sharp and internal foliation is discordant to foliation in the enveloping augen gneiss. Zircons examined from enclaves were highly altered and yielded variable ages that were deemed unreliable.

A sample collected from a large road cut on US 25 just south of the SC-NC state line in the Zirconia 7.5-minute quadrangle (mentioned above) is part of a package of biotite gneisses, biotite schists, and minor calcsilicate gneiss of the Tallulah Falls Formation. This moderately to poorly foliated biotite gneiss with blocky microcline porphyroblasts (quartz, microcline, biotite, plagioclase, hornblende) is multiply folded and displays transposed foliation. In contrast to the Table Rock gneiss, the Tallulah Falls formation sample contained zircons that had cores dating from Mid to Late Proterozoic. Such an abundance of cores suggests a sedimentary protolith for the Tallulah Falls Formation. The presence of zircons with cores ranging in age from Mid to Late Proterozoic implies the involvement of Proterozoic crust in Ordovician granitic magma genesis. Structural relationships indicate Seneca thrust motion post-dated the age of these gneisses.

## STOPS AND DESCRIPTIONS

The directions start at the New Liberty Church on US Hwy 25 north of Greenville, SC.

0.0 Miles: Go north on US-25 N

0.3 Miles: Turn right at SC 414 E

4.3 Miles: Turn right at SC 253/Mountain View Rd

4.6 Miles: Slight left at Camp Creek Rd/County Rd 569

6.0 Miles: Turn left at Packs Mountain Ridge Rd

7.0 Miles: **Stop 1.** Pax Mountain. Road sign says "Packs Mountain Road". Tigerville quadrangle.

This vantage point provides a spectacular view north toward the Escarpment and homes of The Cliffs at Glassy community. The conspicuous bald is Round Mountain (summit 850 m). To the right is broadly flat-topped Hogback Mountain, with its WSPA broadcast towers. Summit elevation is 3211 feet (about 975 m). Antenna height is 459 ft; a severe ice storm with high winds in February 2009 caused the older transmitter towers to collapse. Between 1926 and 1933, the developer of the “Blue Ridge Forest” built a golf course, a pond, and roads for home sites atop Hogback Mountain and the ridge to the west. Upon his death the project was abandoned, with just one lot sold to an artist (Edgar Woodfin, personal communication). We will have lunch later on Glassy Rock at the top at the flagpole.

Pax Mountain (Figures 1 and 3, stop 1) is a steep N65°E ridge (maximum elevation 415 m) in Tigerville quadrangle rising above the surrounding Piedmont (Figure 4). Numerous northeast-trending lenses of resistant siliceous cataclastic rocks (SCR) are arranged in east-northeast, right-stepping patterns and form one or two zones along the Pax ridge crest and flanks. Their geometry indicates sinistral faulting. Our experience mapping SCR indicates they normally indicate the immediate proximity of younger faults (even if these are “no see-ums”); damage zones and slickenlines related to the younger faults may deform the SCR bodies. Many springs on both sides of the ridge are present and aligned along the northeast trace of these younger faults. Spring locations are an aid in tracing the faults laterally when mapping.



Figure 4. Low-angle aerial view to the north of the Blue Ridge Front. The peak on the skyline to the right is Hogback Mountain. Linear Pax Mountain in the middle distance is the most prominent topographic feature in central Tigerville quadrangle. Photo taken in 1984.

The Pax Mountain fault lies between the two parallel zones of SCR bodies on Figure 3. The Walhalla nappe (grgn map unit), the Six Mile thrust sheet (TF map unit), and the intervening ductile Seneca thrust, are repeatedly offset by a dominant set of N60°-75°E faults in Tigerville quadrangle; both oblique, left- and right-lateral offsets are produced by that fault set. Groundwater exploration in fracture zones of crystalline metamorphic bedrock was



described for the upstate Piedmont by Snipes (1981) and Snipes and others (1984). Geologic and hydrologic conditions associated with drilling water wells and yields at Pax Mountain were described by Snipes and others (1986). Kaolinitic clay (presumably weathered fault gouge) along fractures inhibited water flow and yield. Local people are well aware of the kaolinitic clay in their wells, and they aptly refer to it as ‘mountain lard’.

Leaving Stop 1, continue east on Pax Mountain Ridge Road for 0.7 miles.

7.7 Miles: Turn left at SC 101 N

8.1 Miles: Take the 1st right toward County Rd 277/Jordan Rd

Go ~100 feet: Turn right at County Rd 277/Jordan Rd

9.2 miles: Take the 2nd left onto County Rd 560/S. Glassy Mountain Rd

9.4 Miles: Take the 1st right onto County Rd 114/Pleasant Hill Rd

11.3 Miles: **Stop 2.** Campbell Covered Bridge. Tigerville quadrangle.

Campbell Covered Bridge across Beaverdam Creek is the last remaining covered bridge in South Carolina (Figure 5).



Figure 5. Campbell's covered bridge across Beaverdam Creek. View to the north.

Built in 1909 and restored in 1964 and 1990, it is a four-span Howe truss bridge, featuring diagonal timbers and vertical iron rods. The locality is now part of a county park. Pavements along the creek beneath the bridge expose Mush Creek (biotite-microcline augen) gneiss. The rock shows no mylonitic (ductile or sheared) textures. Its relationship to the sheared biotite augen gneiss we will see at The Cliffs (stops 8, 9, and 10) is unknown. A northeast fault passes near here, offsetting the trace of the Seneca thrust mentioned previously.

From Stop 2 continue northeast on Pleasant Hill Road for 0.4 Miles

11.7 Miles: Turn right at S Carolina 414 E

12.8 Miles: Turn left at S Carolina 14 W

18.2 Miles: Turn right at S 183/S Blackstock Rd/State Rd S-42-183

18.6 Turn left at Hub Wilson Rd/State Rd S-42-1735

18.7 Miles: **Stop 3.** Faith Baptist Church. Please do not dig in this exposure! Landrum quadrangle.

At this stop behind Faith Baptist Church (Figure 6) we see a brittle normal fault in saprolitic, differentially weathered, leucocratic mica-quartz-feldspar granitoid gneiss and amphibolite of the Tallulah Falls Formation. Several irregular, discordant biotite amphibolite (mafic) dikes appear to the right of the fault as brown streaks. Near the top of the exposure, left of the fault, layers of reddish, iron-stained biotite quartzo-feldspathic gneiss are down-dropped. This is the sort of exposure where a ‘piedmont tool’ (a hoe) or a heavy rainstorm come in handy to help view details of the weathered bedrock! The bedrock is complexly folded.

Time permitting, we will walk a short distance uphill behind the exposure to see several well-exposed cataclastic rock bodies up to 1.5 meters wide oriented N75°-85°E. Rock textures indicate multiple episodes of brittle fracturing, brecciation, syntaxial veining, and further opening and re-opening of extensional features. There has been abundant growth of euhedral “comb” quartz crystals in open spaces and cavities generated by the recurrent movements. Near the church an unusual comb-quartz (multiple syntaxial growth) vein a few meters wide has been traced several kilometers northeastward. Farther south, another prominent zone of numerous cataclastic rock bodies and comb-quartz veins runs across Landrum quadrangle (Garihan, 2009a) (Figure 3, shaded region). It lies along the continuation of the Cross Plains fault (Snipes and others, 1979) to the southwest in Slater quadrangle.

Cataclastic rocks in northwest South Carolina and adjacent North Carolina were studied initially by Birkhead (1973) and later described by Garihan (2009b), Garihan and Ranson (1988, and earlier references therein), and Garihan and others (1988, 1990). Inner Piedmont mapping by Villard Griffin (1974) and compilations of regional cataclastic zones by D. S. Snipes in the 1980’s were instrumental in first showing the regional extent of the cataclastic rock bodies. Identical cataclastic rocks and brittle faults of northeast and east-northeast trends are found in the Lake Murray dam area and in Piedmont inliers near the



erosional edge of the Upper Coastal Plain between Aiken and Columbia, SC. Movement is interpreted to be Late Cretaceous-Cenozoic in age and due to reactivation along the Eastern Piedmont fault system (Nystrom, 2006). Joint and fracture data of Bartholomew and others (2009) suggest a complex chronology of Cenozoic fault movements affecting Cenozoic coastal plain rocks. The siliceous cataclastic rocks are probably part of this tectonic history, although we consider their age(s) (Mesozoic? Cenozoic? both?) not to be firmly established everywhere they occur. Hundreds of cataclastic zones occur throughout the Piedmont between Georgia and northern North Carolina, and their origin and regional tectonic significance is a major unsolved problem in the geologic history of the Carolinas.



Figure 6. Exposure of the brittle fault at Faith Baptist Church, Tallulah Falls Formation. The fault is oriented N75°E, 77°W, similar to other brittle faults in the quadrangle. A steep, limonite-weathered mafic dike on the right side of the photo crosses foliation in complexly folded and intruded gneiss. Left to right for scale, geologists are Molly Long, Amber Ciravolo, Rhonda Chan Soo, and Alyssa Wickard.

From Stop 3 retrace your route back to Blackstock Road.

18.8 Miles: Turn right at S 183/S Blackstock Rd

19.2 Miles: Turn left at SC 14 W

22.4 Miles: Turn right at SC 11

28.0 Miles: Turn right at Plumley Summit Road

Go 100 yards to the Cliffs at Glassy Development guard station. You will need permission to enter beyond this point. For the rest of the stops, refer to Figure 7 for directions.

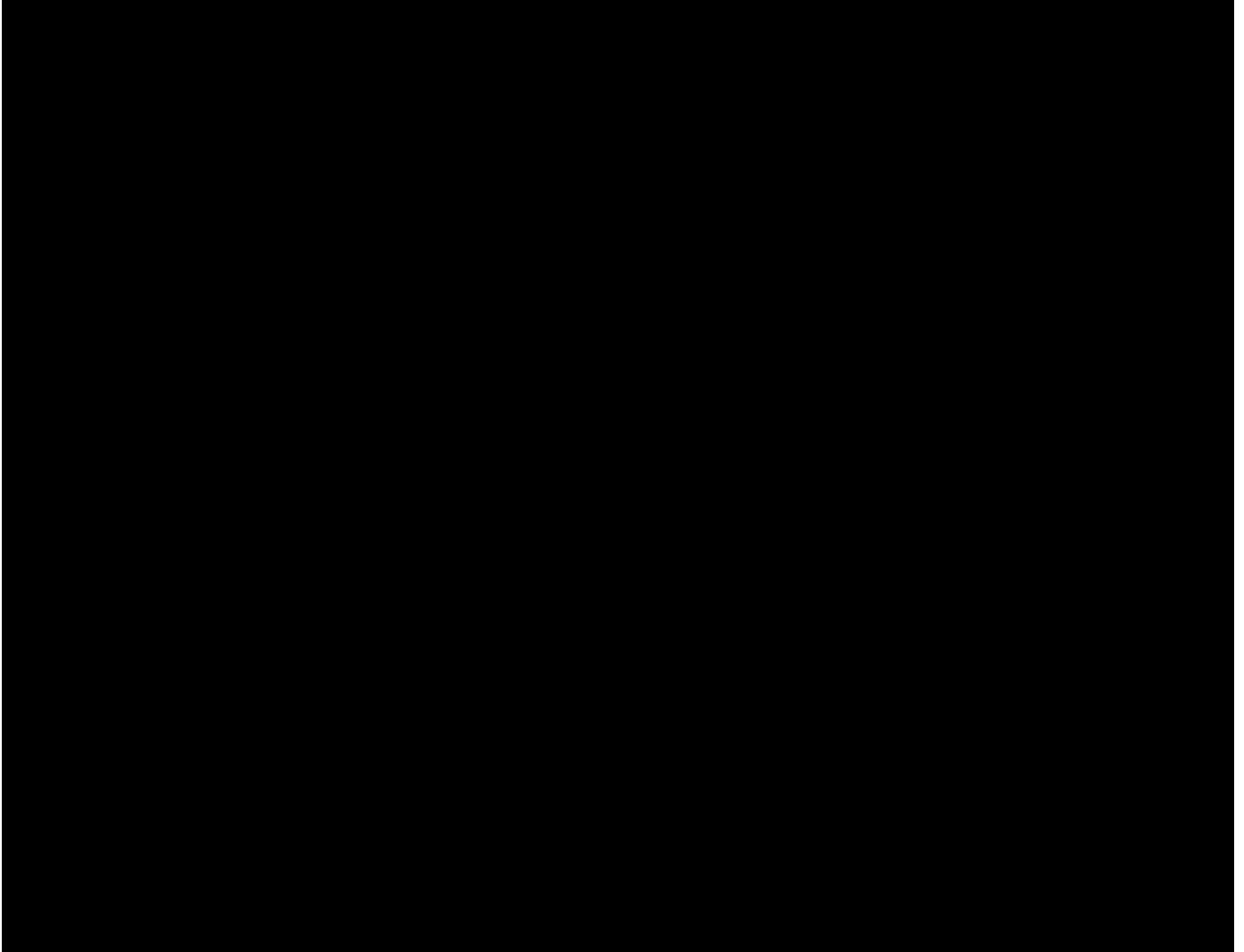


Figure 7: Location of Stops 4-11 in the Cliffs of Glassy Development.

**Stop 4.** Glassy Rock overview. Flagpole and pavillion. Lunch stop. Saluda quadrangle.

This stop is located at the top of the cliffs that we could see from Stop 1 this morning. The elevation at this stop is 840 m. Picturesque views to the south show the rolling Piedmont landscape. The linear ridge at Pax Mountain and Paris Mountain with its communication towers are visible. Stop 4 is located on Figures 1, 3 ,7, and 8.



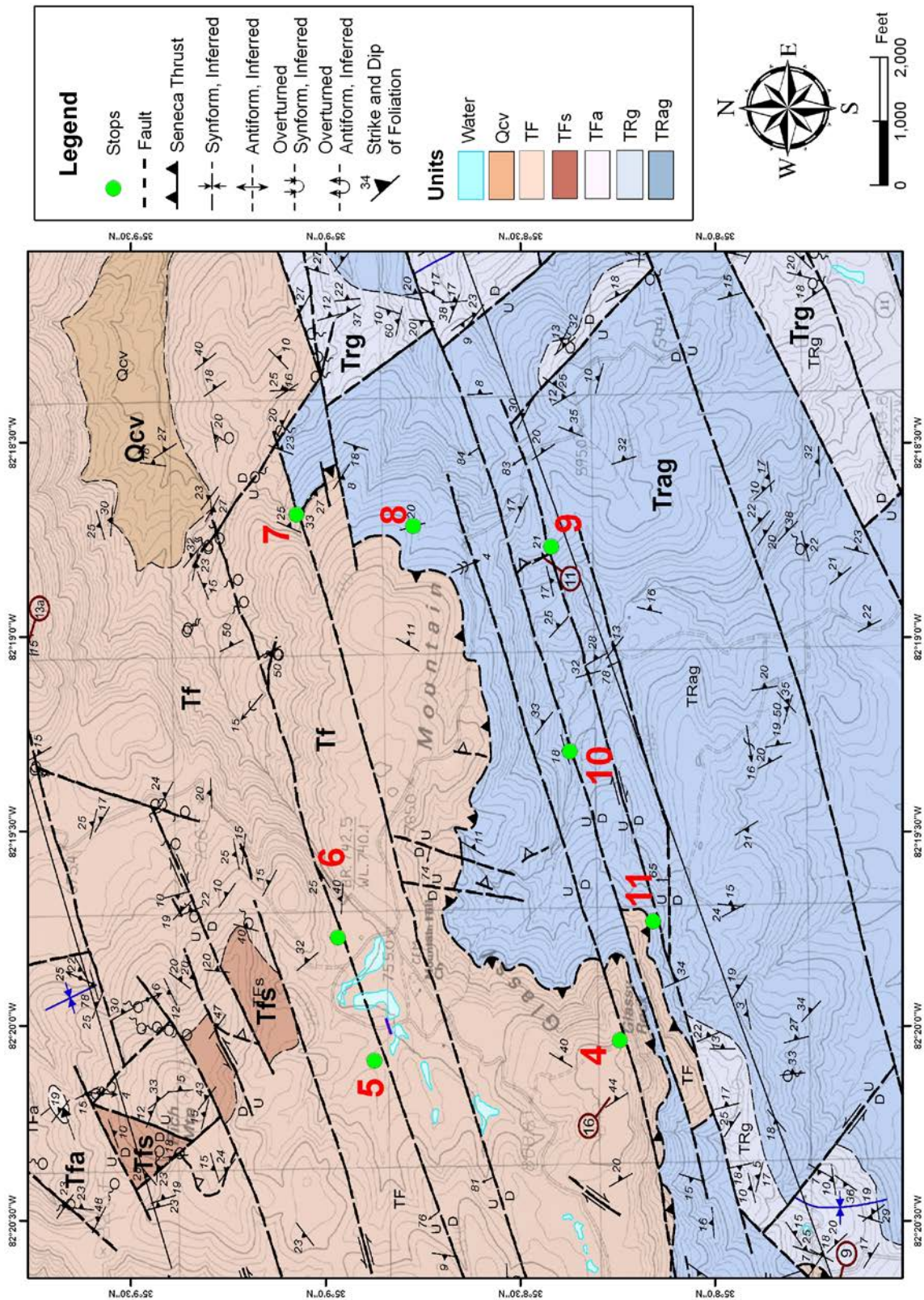


Figure 8. Geologic map of the Glassy Mountain area, showing the sinuous trace of the Seneca thrust fault on its south-facing slope and the major northeast faults locally offsetting it. Trag and Trg units occur in the Seneca thrust footwall; Tf, Tfs and Tfa are hanging wall rocks that lie above the thrust.



Pavements adjacent to the pavillion expose Tallulah Falls Formation rocks, which structurally are part of the Six Mile thrust sheet above the Seneca fault. The resistant, more homogeneous-looking, poorly layered biotite granitoid gneiss here is of igneous origin (Figure 9). Within it one can see scattered, lenticular and irregular xenoliths of biotite quartzo-feldspathic gneiss. Occasional layers of equigranular calc-silicate rock (epidote, quartz, amphibole, garnet) occur within the contorted biotite quartzo-feldspathic gneiss xenoliths. There are also floating, disaggregated blocks of calc-silicate rock in the biotite granitoid gneiss pavements (Figure 10). Calc-silicate rocks are common in the Tallulah Falls Formation regionally; they form coherent quartzose float pieces at the surface when all other rock types have been deeply weathered and are difficult to identify.



Figure 9. Tallulah Falls Formation gneiss exposures on the south face of Glassy Rock. Stop 4 overlook. View to the west.

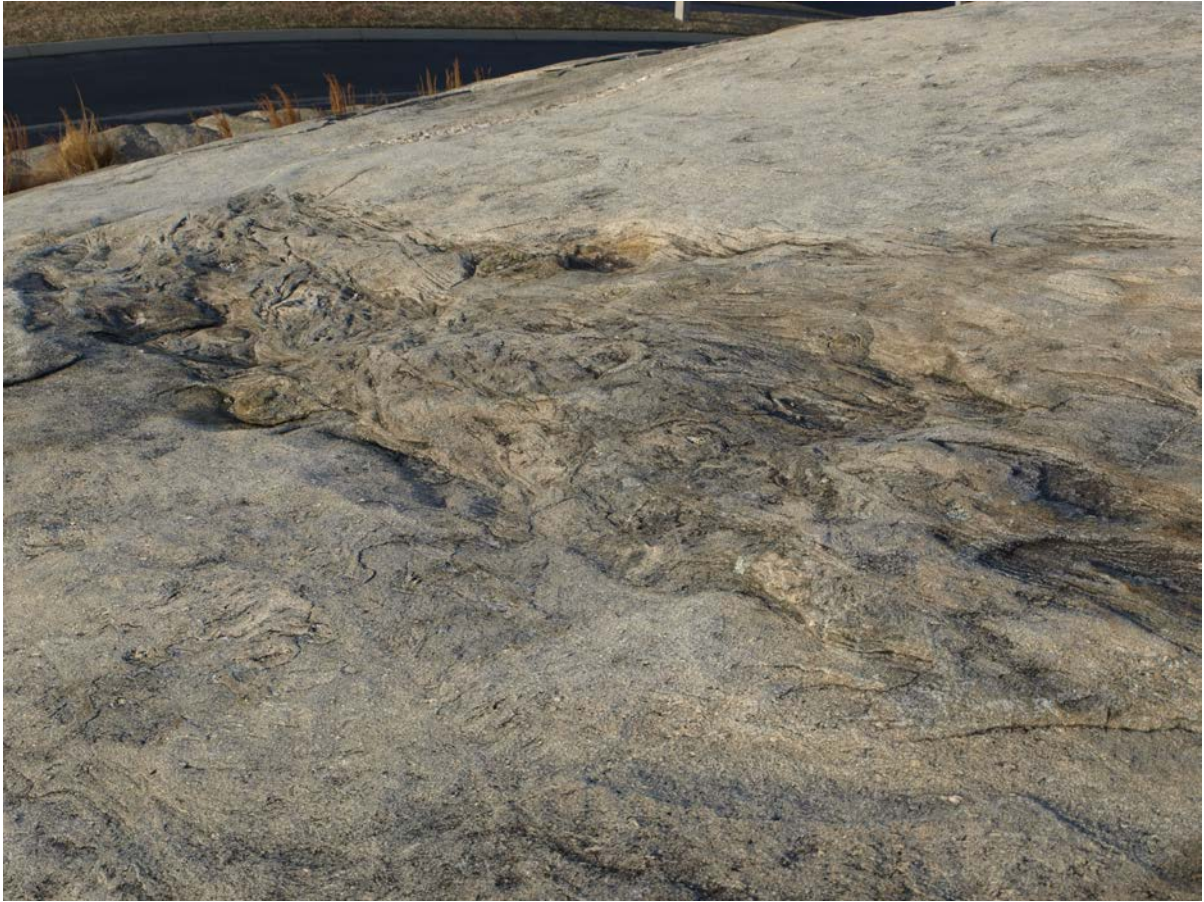


Figure 10. Glassy Rock. Large xenolith (~14 meters long) of compositionally layered biotite quartzo-feldspathic gneiss with scattered internal blocks and disrupted layers of resistant calc-silicate gneiss. The xenolith has digitated margins where in contact with surrounding intrusive biotite granitoid gneiss (left side of photo). Conspicuous pale green epidote-rich compositional layers are present in the individual blocks. The epidote-rich blocks represent stiffer calc-silicate layers in the gneiss boudinaged during deformation and intrusion of the enveloping biotite granitoid gneiss. A small pegmatite cuts the xenolith at the north end of the xenolith. View to the east.

**Stop 5.** Golf course wells near the Clubhouse, The Cliffs at Glassy. Saluda quadrangle.

The Cliffs at Glassy Water System serves over 800 service connections as well as the golf and clubhouse facilities within The Cliffs at Glassy Development. The water system covers an area of approximately 6 square miles. The system was originally constructed by The Cliffs Communities, Inc. during the early 1990's prior to the initial development and sale of residential lots. Ownership and operation of the system was then transferred to the Blue Ridge Rural Water Company (BRRWC) of Greer, SC. Blue Ridge's "Piedmont System" serves a large portion of northern Greenville County and spans from the Greenville/Spartanburg County line to the east to U.S. 25 to the west. The steep slopes flanking The Cliffs at Glassy development preclude BRRWC from pumping water supplies from their contiguous service area at S.C. Highway 11. Consequently, BRRWC currently



utilizes bedrock wells that are located within the elongated valley that is present at the top of Glassy Mountain to supply water to The Cliffs community.

A total of 18 wells have been constructed within The Cliffs at Glassy wellfield, although only 9 wells are currently in service (Table 1, Figure 11). Many of the drilled wells were never developed as production wells because of low yields. The valley within which the wells are drilled trends southwest-northeast parallel to the headwaters of the South Pacolet River. This trend is also roughly parallel to the prevalent orientation of mapped faults within the Golf Course area. Relatively thick layers of regolith and saprolite (38 to 92 feet) overlie the bedrock within the wellfield and serve as important reservoirs of groundwater storage for the aquifer system atop the mountain.

<b>Well Name</b>	<b>Depth (ft bgs)</b>	<b>Casing Depth (ft bgs)</b>	<b>Pumping Rate (gpm)</b>	<b>Drawdown @ 24 hrs (ft)</b>	<b>Specific Capacity (gpm/ft)</b>
Well # 4	500	39	81	69	1.17
Well # 8	405	75	52	323	0.16
Well # 11	505	51	37	439	0.08
Well # 12	475	76	23	423	0.05
Well # 13	425	54	27	364	0.07
Well # 14	405	92	25	351	0.07
Well # 16	350	58	73	206	0.35
Well # 19	602	38	75	133	0.56
Well # 20	873	54	90	168	0.54

Table 1. Physical parameters derived from SC DHEC 24-hour pumping test results of the nine current production wells within The Cliffs at Glassy. Well and casing depths are from drillers' logs and are below ground surface (bgs).

The permitted capacity of the existing Cliffs at Glassy Water System is approximately 562,000 gallons per day. In recent years, The Cliffs at Glassy Mountain community's water supply has been inadequate as development has progressed and new users have been added to the system. Water usage has also increased with the proliferation of drought intolerant landscapes throughout the development. Two (Wells #19 and #20) of the nine wells in use have been put online within the last two years and intersect productive bedrock fractures at depth (600 feet or more). BRRWC has also instituted separate metering for lawn irrigation and scaled rates for water use in order to encourage conservation of their supplies.

#### **Stop 6.** Water processing facility, The Cliffs at Glassy. Saluda quadrangle.

The Blue Ridge Rural Water Company has recently completed construction of a new groundwater treatment facility for The Cliffs at Glassy Water System. The treatment capacity of the new plant is over 800,000 gallons per day over the previous treatment capacity of

roughly 500,000 gallons per day. Raw groundwater is directed here from BRRWC's wells for disinfection and pH adjustment prior to being pumped to finished water tanks at Rich Mountain at the northern extremity of the development. Mr. Ross Gosnell, Operations Manager for BRRWC, will provide a brief tour of the new treatment facility and answer any questions concerning the groundwater treatment and finished water transmission process.

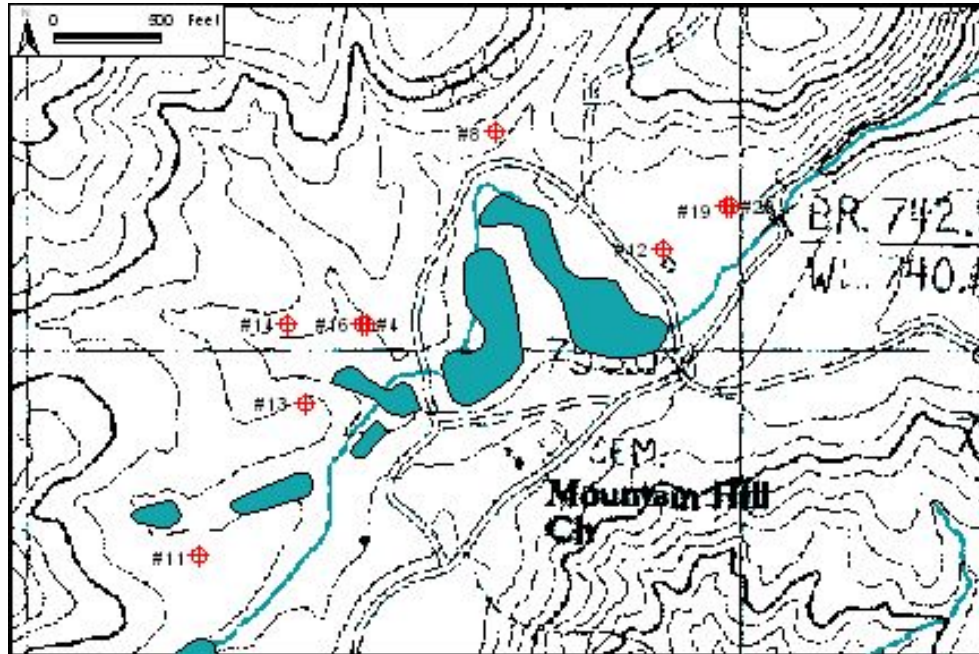


Figure 11. Locations of production wells currently in use for The Cliffs at Glassy Water System.

**Stop 7.** Foggy Cut Lane exposures, east side of Glassy Mountain.

Several steep exposures of biotite augen gneiss (Trag) and Tallulah Falls gneiss (Tf, Figure 8) occur along Foggy Cut Lane as the road descends the steep east slope of Glassy Mountain. Near the road bend and falls one can see a cross section through en echelon joints, fractures, and faults of northeast trend (Figure 12). These and nearby parallel faults offset the trace of the Seneca fault, which is generally located on the hill slope above this stop. One major fault that passes through here can be traced about 5 km southwestward. The joints, fractures, and faults structures we see here influence the flow of water in the Glassy Mountain-Golf Course area. Outcrops also show west-vergent, tight to overturned folds and a discordant, sheared mafic dike (?) in mylonitic gneiss discordant to its foliation.



Figure 12. Two epidote-coated, planar faults or reactivated joint surfaces, right of the notebook. Stop 7. The surfaces are oriented N55°-56°E, dipping 75°-78°NW (toward the right). Slickenlines on these surfaces plunge 14°-37° northeast; risers indicate oblique-normal (dextral) movements. Other similarly oriented faults in the exposure show slickenlines associated with oblique-normal (sinistral) movements.

**Stop 8.** Transposition structures in biotite augen gneiss, Hawk Springs Drive. Saluda quadrangle.

Since stops 4, 5, and 6, we have crossed the trace of the ductile Seneca fault (Figure 8) into rocks below it in the footwall. We see here well-exposed transposition structures and extensional crenulation cleavage in biotite augen gneiss described in detail by Howard (2001). Transposition is a process that partly realigns S-surfaces (here foliation in gneiss) into similar or different orientations, forming a zone with a newer gneissic foliation. At this location the older foliation is contorted into northwest-vergent chevron folds. Their limbs are transposed or cross-cut locally by zones where a new foliation has developed. The new foliation has utilized the same fabric elements in the rock (pink feldspar augen, quartz, and biotite), and they have undergone crystal plastic deformation and recrystallization. In Figure 13, older foliation surfaces are approximately horizontal and more widely spaced. The C' shear bands cross cut transposition zones of ductile deformation. The C' shear bands are





Figure 13. Transposition and extensional crenulation cleavage structures in biotite augen gneiss, Hawk Springs Drive.

parallel to the hammer handle, running from upper left to lower right, and within the bands the foliation surfaces are more closely spaced. Shear sense of movement along extensional crenulation cleavages (C' shear bands) is consistently down to the south (right). The photogenic exposure has world-class ductile deformation features! We will see more mylonite in this rock unit in stop 9.

In the Glassy Mountain area, numerous exposures have zones that represent particularly intense shearing localized with sharp contacts adjacent to coarser-crystalline, less sheared mylonitic biotite augen gneiss. In the less sheared mylonite, feldspar augen with modified shapes normally are a few centimeters in long dimension. However, in the high strain zones, closely spaced, planar compositional layers occur with feldspar augen porphyroclasts that have been dynamically reduced to small lenticular crystals with high aspect ratio (length divided by width). They are less than 1 cm in length sitting in a matrix of fine-crystalline, recrystallized material. The texture of the rock locally borders on an ultramylonite (less than 10% of the original K-feldspar porphyroclasts are preserved). Therefore, within the Trag footwall unit, high-strain, planar zones exist where more intense shearing and ductile deformation has been concentrated compared to adjacent mylonitic biotite augen gneiss. One interpretation for the cause of the ductile shearing and variable mylonitization of the augen gneiss is the westward emplacement of the overriding ductile



Seneca fault during Taconic or Acadian deformation of the southern Appalachian orogen. Clearly not all the movement associated with the emplacement of the ductile Seneca thrust took place in or near the thrust surface. It was distributed also into planar zones within the footwall rocks beneath it. Movement along extensional crenulation cleavages consistently down to the south may be related to collapse of a tectonically-thickened orogenic wedge at a time following ductile thrusting.

We correlate the biotite augen gneiss we see on this trip with the biotite augen gneiss at Bald Rock along Route 276 in the Cleveland quadrangle. Age dating of the biotite augen gneiss at Bald Rock has been done by Ranson and others (1999) (see Geochronology of Gneisses discussion above).

**Stop 9. Mylonitic biotite augen gneiss, High Rock Ridge Drive. Saluda quadrangle.**

At stop 9 (Figure 14) several relatively unweathered exposures of biotite augen gneiss along High Rock Ridge Drive show the mineralogy and textural characteristics of the mylonitic gneiss. Pink K-feldspar porphyroclasts up to 4 cm with white rims of myrmekite (plagioclase + quartz intergrowths) are modified by ductile shearing deformation into shapes ranging from rounded rectangles to lenses. Small tails or wings of recrystallized,



Figure 14. Mylonitic biotite augen gneiss roadcut along High Rock Ridge Drive, stop 9.



fine-crystalline quartz and feldspar extend from the tapered ends of the porphyroclasts (Figure 15). In the appropriate viewing direction of individual porphyroclasts, the asymmetric shapes of the wings (sigma structures) indicate shearing along foliation surfaces was top to the left or west during deformation. Shearing has also produced thin, flattened quartz-feldspar aggregates aligned parallel to foliation. Specular hematite has been found at this exposure.

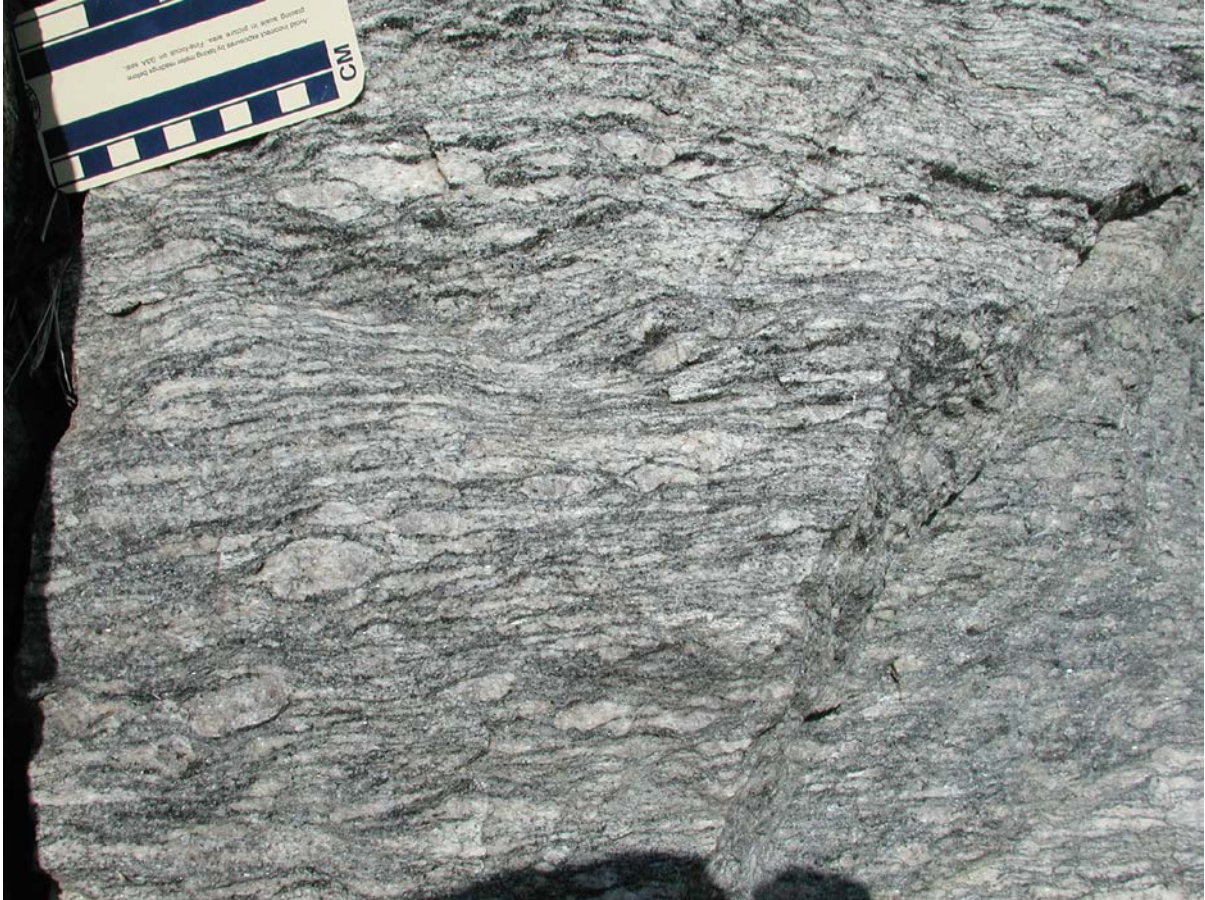


Figure 15. Shear sense indicators in mylonitic biotite augen gneiss, High Rock Ridge Drive. Extensional crenulation cleavage surfaces (C' shear bands) also are present.

**Stop 10.** Alcove, Rock Shoals Drive. Saluda quadrangle.

Stop 10 is located on Figure 1. The stop lies at the foot of a large embayment in the trace of the Seneca fault (Figure 8), produced by streams headwardly eroding back into the foot of the Escarpment. The streams flow on bedrock, an indication of their active downcutting in the area.

The alcove is a long overhang in weathered biotite augen gneiss (Figure 16). At this location abundant quartzo-feldspathic granitoid is interlayered with the gneiss. Differential weathering has accentuated the compositional differences present in the rock. The more resistant micaceous layers parallel to foliation stand out in relief on weathered surfaces.



Based on our previous encounters with the augen gneiss today, the trip participants will recognize some familiar features: west-vergent, overturned chevron folds here affected by broad warps or folds in the gneissic foliation, ductile shear zones, transposition zones, brittle faults, joints, and granitic intrusive bodies.



Figure 16. Alcove in biotite augen gneiss, Rock Shoals Drive, stop 10.

Near the east side of the alcove a small reverse fault oriented N50°W has ~8 cm of reverse offset (Figure 17). The northwest faults are an important component of the regional brittle fault pattern (Figure 17) where they can be mapped. Normally they terminate against the northeast faults. Also found in the exposure are ductile shear zones (Figure 18) which pre-date the brittle faults. These features and those seen at Hawk Springs Drive (Stop 8) indicate down-to-the-southeast (right) normal (extensional) movement, possibly the result of gravitational collapse of a thick stack of hot ductile thrust sheets developed in the Inner Piedmont orogenic wedge during earlier collisional orogeny.





Figure 17. Small northwest-striking reverse fault at the Alcove, Rock Shoals Drive.



Figure 18. Ductile shear zone indicating down-to-the-right normal-sense extensional movements. Alcove, Rock Shoals Drive.

**Stop 11.** Seneca fault, Plumley Summit Road, southeast of Glassy Rock. Saluda quadrangle.

If time allows, we will visit an exposure of the Seneca fault on Plumley Summit Road. This roadcut serves to show what the trace of the Seneca fault looks like in a typical outcrop. The exposure has been studied in detail by Warlick and others (2001). The following is abstracted from their descriptions.

The lower portion of the exposure contains rootless, recumbent isoclinal and disharmonic folds. Grain-size reduction due to dynamic recrystallization has produced a fine-crystalline mylonitic gneiss below the ductile Seneca fault surface, with accompanying progressive shearing and flattening of augen upward to the contact. A slightly discordant foliation in mylonitic gneiss marks the fault position at about the grassy interval near the top of the exposure.

Subvertical northeast-striking faults cut the exposure at the west end of the roadcut; slickenlines and risers indicate right-lateral, down-to-the-north motion. The right-lateral faults locally offset east-striking faults with slickenlines and risers indicating down-to-the-south movement. Multiple N50°-80°E faults parallel the steep slope below Glassy Rock; their traces locally are marked by springs.

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Our interest (JMG, WAR) in mapping the Piedmont faults and cataclastic rocks was initiated in the early 1980's by encouraging comments of our friend, Dave Snipes and by field excursions led by Villard Griffin.

## REFERENCES

- Bartholomew, M. J., Evans, M. A., Rich, F. J., Brodie, B. M., and Heath, R. D., 2009, Rifting and drifting in South Carolina: Fracture history in Alleghanian granites and coastal plain strata: Carolina Geological Society, 2009 Annual Meeting Field Trip, Columbia, South Carolina, 51 p.
- Birkhead, P. K., 1973, Some flinty crush rock exposures in northwest South Carolina and adjacent areas of North Carolina: South Carolina Geological Survey, South Carolina State Development Board, Geologic Notes, v. 17, n. 1, p. 18-25.

Clendenin, C. W., and J. M. Garihan, April 2001. Timing of brittle faulting on Pax Mountain: a chicken or the egg question applicable to Piedmont mapping: Geological Society of America Abstracts with Programs, v. 33, n. 2, p. A-18.

Doar, W. R., III, 1998. Geologic Map of the Tigerville 7.5-minute quadrangle, South Carolina. South Carolina Department of Natural Resources Open-File Report 110.

Fullagar, Paul D., Goldberg, Steven A., and Butler, J. Robert, 1997, Nd and Sr isotopic characterization of crystalline rocks from the southern Appalachian Piedmont and Blue Ridge, North and South Carolina: *in* Sinha, A. Krishna, Whalen, Joseph B., Hogan, and John P., eds., The Nature of Magmatism in the Appalachian Orogen, Geological Society of America Memoir 191, p. 165-179.

Garihan, J. M., 2009a, Geologic map of the Landrum 7.5-minute quadrangle, Greenville and Spartanburg Counties, South Carolina: South Carolina Department of Natural Resources, Geological Survey, Geological Quadrangle Map 44, 1:24,000 scale.

Garihan, J. M., 2009b, Geology of the Jocassee Gorges, Mountain Bridge Area, and Northwestern South Carolina in Greenville, Oconee, and Pickens Counties, South Carolina: SCDNR, South Carolina Geological Survey, Open File Poster OPF-03-09. (Geologic map covering South Carolina portion of thirteen 7.5-minute quadrangles.)

Garihan, J. M., and Ranson, W. A., 1988, Structure of the Marietta-Tryon graben, South Carolina and adjacent North Carolina: *in* Bartholomew, M. J., Hyndman, D. W., Mogk, D. W., and Mason, R., eds., Basement Tectonics 8: Characterization and comparison of Ancient and Mesozoic continental margins, Proceedings of 8<sup>th</sup> International Conference on Basement Tectonics (Butte, Montana), Kluwer Academic Publishers, Dordrecht, The Netherlands, p. 539-555.

Garihan, J.M., Ranson, W.A., Preddy, Mark, and Hallman, Treg, 1988, Brittle faults, lineaments, and cataclastic rocks in the Slater, Zirconia, and part of the Saluda 7 1/2-minute quadrangles, northern Greenville County, SC and adjacent Henderson and Polk Counties, NC: *in* Secor, D., Jr., ed., Southeastern Geological Excursions Guidebook, S.C. Geological Survey, p. 266-350.

Garihan, J. M., Ranson, W. A., Orlando, K. A., and Preddy, M. S., 1990, Kinematic history of Mesozoic faults in northwestern South Carolina and adjacent North Carolina: South Carolina Geology, v. 33, no. 1, p. 19-32.

Garihan, J. M., Clendenin, Jr., C. W., and Doar, III, W. R., 2009, Geologic map of the Tigerville 7.5-minute quadrangle, Greenville County, South Carolina: South Carolina Department of Natural Resources, Geological Survey, Geological Quadrangle Map 45, 1:24,000 scale.



Griffin, V. S., Jr., 1974, Analysis of the Piedmont in northwest South Carolina: Geological Society of America Bulletin, v. 85, p. 1123-1138.

Hallman, Tom, September 1981, "Water, Water Everywhere?", Clemson World, v. 34, n. 3, p. 2 – 7.

Howard, C. Scott, 2001, Transposition structures on Glassy Mountain, Saluda 7.5-minute quadrangle, Greenville County, South Carolina: *in* Garihan, J. M., and Ranson, W. A., eds., Geology of the Inner Piedmont in the Caesars Head and Table Rock State Parks area, northwestern South Carolina, South Carolina Geology, v. 43, p. 25-35.

Nystrom, Paul G., Jr., 2006, Late Cretaceous-Cenozoic brittle faulting beneath the western South Carolina Coastal Plain: Reactivation of the Eastern Piedmont Fault System, Geological Society of America, Abstracts with Programs.

Ranson, W. A., Williams, I. S. and Garihan, J.M., 1999, Shrimp zircon U-Pb ages of granitoids from the Inner Piedmont of South Carolina: Evidence for Ordovician magmatism involving mid to late Proterozoic crust: Geol. Soc. America Abstracts with Programs, v. 31, n. 7, p. A-167.

Snipes, D. S., Burnett, L. L., Wylie, J. A., Sacks, L. A., Heaton, S. B., Dalton, G.A., and Israel, B. A., 1984, Indicators of ground water quality and yield for a public water supply in rock fracture zones of the Piedmont: Technical Completion Report G-868-02, Water Resources Research Institute, Clemson University, 80 p.

Snipes, D. S., Manoogian, P. R., Davis, M. W., Burnett, L. L., Wylie, J. A., Heaton, and S. B., 1986, Ground-water problems in the Mesozoic Pax Mountain fault zone: Ground Water, v. 24, n. 3, p. 375-381.

Snipes, D. S., 1981, Groundwater quality and quantity in fractures zones in the Piedmont of northwestern South Carolina: Clemson University, Water Resources Research Institute Report 93, 87 p.

Snipes, D. S., Davis, M. W., and Manoogian, P. R., 1979, Cross Plains fault in Piedmont of northwest South Carolina: Geological Society of America, Abstracts with Programs, v. 11, no. 4, p. 213.

Soricelli, A., C. W. Clendenin, and J. W. Castle, March 2003, Geologic mapping of the Anderson South 7.5-Minute Quadrangle, Anderson County, South Carolina: Geological Society of America Abstracts with Programs.

Warlick, Cameron M., Clendenin, C. W., and Castle, James W., 2001, Geology of The Cliffs at Glassy development, southern Saluda 7.5-minute quadrangle, Greenville County, South Carolina: *in* Garihan, J. M., and Ranson, W. A., eds, Geology of the Inner Piedmont in the Caesars Head and Table Rock State Parks area, northwestern South Carolina, South Carolina Geology, v. 43, p. 37-47.

Warner, R.D., D. S. Snipes, S. S. Hughes, J. C. Steiner, M. W. Davis, P. R. Manoogian, and R. A. Schmitt. 1985. Olivine-normative dolerite dikes from western South Carolina: mineralogy, chemical composition and petrogenesis: *Contributions to Mineralogy and Petrology*, v. 90, n. 4, p. 286 – 400.

Warner, R. D., D. S. Snipes, L. L. Burnett, J. A. Wylie, L.A. Sacks, and J. C. Steiner, 1986, Shoals Junction and Due West dolerites, South Carolina: *Southeastern Geology*. v. 26, p. 141-152.